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This paper recounts the conventional geodetic accomplishments of the Defense Mapping Agency (DMA) and its predecessor organizations in Africa, beginning with the 30th Meridian Arc in the early 1950's and continuing through the 12th Parallel Survey, which was completed in 1970. Additionally, it identifies the modernization resulting from the many Doppler geodetic positions, referenced to DMA's precise Navy Navigation Satellite ephemerides, established to date throughout the continent. Further, it provides a conceptual plan for accomplishing, through bilateral agreements with the countries involved

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DMA SUPPORT TO A UNIFIED GEODETIC DATUM
FOR THE AFRICAN CONTINENT

by

Kenneth I. Daugherty, Ph.D.

Defense Mapping Agency

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ABSTRACT

This paper recounts the geodetic projects successfully completed with the help of African nations by the Defense Mapping Agency (DMA) and its predecessor organizations in Africa, beginning with the 30th Meridian Arc in the early 1950's and continuing through the 12th Parallel Survey in 1970. It also identifies the modernization resulting from the many Doppler geodetic positions, referenced to DMA's precise Navy Navigation Satellite ephemerides, established to date throughout the continent. Further, it provides a conceptual plan for accomplishing, through bilateral agreements with the countries involved, the unification of the various African datums by means of future Doppler geodetic positioning. These Doppler positions can also contribute to the establishment of zero order nets.

DMA SUPPORT TO A UNIFIED GEODETIC DATUM
FOR THE AFRICAN CONTINENT

The geodetic survey networks of Africa are currently referenced to three major and approximately 27 minor datums employing two different reference ellipsoids. A sizeable area still remains to be surveyed, charted or mapped. We believe a common geodetic datum for Africa is achievable by 1984.

The great work for an Arc of the Meridian measurement to connect Alexandria and Port Elizabeth, as envisioned by Sir David Gill* (1879), took 74 years to become a reality. This backbone chain of triangles spans 67 degrees of latitude and supports many ribs of east-west survey arcs. It is unfortunate that delays in observing Gill's arc along the 30th meridian of east longitude resulted in the geodetic positions being based on three datums: European 50 and Adindan in the north and Arc 50 in the south. The European 50 datum is referenced to the International ellipsoid (1924) while Adindan and Arc 50 datums are on the Clarke 1880 ellipsoid. Both reference surfaces are now recognized as obsolete Earth models.

The second major African geodetic arc follows the 12th Parallel North joining Dakar with Addis Ababa. It spans about 64 degrees of longitude and is referenced to Adindan datum. This 12th Parallel Arc connects extensive national survey networks in Nigeria, Sudan and Ethiopia.

The third major geodetic arc is in the northern part of the continent. It joins Marrakech to Alexandria. This North African Arc encompasses the Mediterranean and Saharan countries of Morocco, Algeria, Tunisia, Libya and Egypt with geodetic positions referenced to European 50 datum.

*David Gill was the Astronomer at the Cape of Good Hope and later became Scientific Advisor to the Geodetic Survey of South Africa.

Three extensive gaps exist in the African geodetic chains. One, in the northwest, extends about 14 degrees between Dakar and Marrakech through Mauritania and Western Sahara. A second geodetic gap is in the west between Dakar and Cabinda, extending about 47 degrees through Guinea-Bissau, Guinea, Sierra Leone, Liberia, Ivory Coast, Ghana, Togo, Dahomey, Benin (excluding remaining Nigeria), Cameroon, Rio Muni, Gabon and Congo. The third, in the northeast, extends about 26 degrees through Somalia and Kenya around the Horn of Africa.

Although it will probably be some time before a large-scale map series is compiled covering the entire continent, it is, however, quite possible that African nations can now exploit modern available techniques to densify and supplement their geodetic surveys to achieve individual national development objectives. One of the revolutionary techniques, e.g., Doppler geodetic positioning system, is extremely suitable for this purpose and the Defense Mapping Agency (DMA) provides a unique service in this respect.

It is appropriate to recount the roles played by the United States through DMA in bringing the geodetic control of Africa to its current state of development. We take pride in the key role we have played in closing the final gap in the 30th Meridian Arc and, also, in measuring the 12th Parallel Arc. This work was executed and guided by the Army Map Service (AMS), the predecessor organization to DMA's Hydrographic/Topographic Center. These AMS activities enjoyed excellent collaboration and assistance from the survey organizations of the host countries.

The 30th Meridian Arc. Beginning on 12 December 1952, an AMS-sponsored project closed a 10-degree gap in the triangulation connecting the Sudan with

Uganda and Zaire (then, Belgian Congo) in two observing seasons. Of the 109 stations occupied, 63 were tower stations with all closures and standard errors satisfying first-order geodetic standards. The preliminary base to base length check, through the stronger chain of triangles, ranged from 1:114,000 to 1:310,000. This final gap in the Arc of the Meridian extended a distance of 630 miles (1014 km) from the Nuba Mountains in the Sudan to the Semliki flats at the southern end of Lake Albert in Uganda and Zaire. Three hundred miles of the project area, in the virtually impassable Sudan region of the Sudan, contain no hills and little change in elevation, making the use of survey towers essential. The 103-foot steel towers provided intervisibility, a very difficult feature of the survey. Haze from burning grasses, fog, then rains and floods were commonplace throughout this difficult campaign. Operations, completed on 27 January 1954, made Sir David Gill's concept a reality. The 30th Meridian Arc was later utilized by DMA in a recalculation of the size and shape of the Earth resulting in the World Geodetic System 1972, published in 1974.

The 12th Parallel Arc. The concept of a 12th Parallel Arc was introduced at a meeting of the Scientific Council for Africa South of the Sahara held in Bukavu, Zaire, in November 1953. A resolution identified the necessity of an arc of the Parallel extending from the east to the west coast of Africa, following more or less the 12th Parallel (north) and tying with the 30th Meridian.

The objective of the 12th Parallel Survey was to establish a first-order geodimeter traverse and geoidal profile along a major parallel in Africa. The intention was to facilitate the integration of local geodetic control systems throughout West Central Africa and to establish the means for

accomplishment of future mapping and geodetic surveys on one continuous major datum and to provide data for future scientific studies of the Earth's size and shape. The 12th Parallel Arc consists of 4,648 kilometers of high-precision traverse, from Dakar, Senegal, to the Chad-Sudan border. The arc passes through Mali, Upper Volta, Niger, Nigeria, Cameroon and Chad, and is one of the most accurate surveys in Africa. Connecting the traverse with triangulation in the Sudan, it became possible to extend the geoidal profile from Dakar to the eastern edge of Ethiopia, i.e., practically the entire breadth of Africa. The traverse survey operations (except in Nigeria) were performed under a contractual agreement with the Institut Géographique National (IGN) of France. Four employees from the Institut National de Topographie (INT) of Mali worked with the IGN survey teams. The Nigeria operations were performed by their Federal Survey Department. The traverse segment was measured in a 40-month time interval (1967-1970) employing uniform survey standards, specifications and most modern instrumentation including the AGA Geodimeter 4D with Retro-directive Prism, the MRA-3 Tellurometer, the Wild T-4 Universal theodolite, the Wild T-3 precision theodolite and the Wild N-3 precision level.

Analysis of the geodimeter and tellurometer measurements, duplicated along traverse legs, reflects excellent agreement as shown in Table 1. The accuracy achieved for the total traverse was better than one part per million.

TABLE 1. Comparison between Geodimeter and Tellurometer Measurements.

AREA	GEODIMETER (meters)	TELLUROMETER (meters)	DIFFERENCE (G-T) (meters)	RATIO ppm
SUDAN-CHAD	898,419.8673	898,419.4824	+0.3849	0.4
NIGERIA	1,201,334.7720	1,201,332.3898	+2.3822	2.0
NIGER-SENEGAL	2,554,507.6161	2,554,507.2263	+0.3898	0.2
TOTAL	4,654,262.2554	4,654,259.0985	+3.1569	0.7

The data reduction was done by IGN (in Paris) and DMA, and the impressive production statistics for the traverse are listed in Table 2.

TABLE 2. 12th Parallel Survey Production Statistics.

Country	Kilometers Traverse	Number of Stations	Laplace Observations	Kilometers Leveling	Towers Erected
CHAD	833	55	28	xx	37
CAMEROON	14	2	1	xx	2
NIGERIA	1201	81	41	630 ¹	58
NIGER	273	.19	9	148 ²	13
UPPER VOLTA	674	47	23	230	28
MALI	925	76	35	300	47
SENEGAL	613	45	21	xx	34
7 Boundary Crossings	115	xx	xx	xx	xx
TOTALS	4,648	325	158	1,308	219 ³

¹This basic leveling was established by Federal Surveys Department as a Nigerian contribution in conjunction with the 12th Parallel Survey.

²This leveling was established by IGN.

³For the entire survey, 67 percent of the stations required use of towers.

In the completion of the 12th Parallel Survey, we have observed the successful merger of personnel, equipment, the skills, and the single purpose of nine nations operating as a common work force toward a common goal.

The Defense Mapping Agency acknowledges the contributions made by Chief R. Oluwole Coker, Director, Federal Survey Department, Nigeria; the local

governments in each participating African country; M. Georges Laclavère, Director, Institut Géographique National, Paris, France; the U.S. State Department diplomatic personnel; as well as Mr. David L. Mills and Mr. John S. McCall, of the Defense Mapping Agency, and all other individuals now deceased or retired. However, the Defense Mapping Agency is especially gratified by the international cooperation which contributed most to the successful conclusion of this project. Continuation of such international cooperation in other areas may eliminate some of the world's major geodetic deficiencies.

Details regarding the Worldwide Geometric Satellite Program, a part of the United States National Geodetic Satellite Program, were presented to the African geodetic community by J. D. d'Onofrio in November 1972 at the Third U.N. Regional Cartographic Conference for Africa, held in Addis Ababa. This presentation discussed the Wild BC-4 ballistic camera observations made in Dakar, Fort Lamy, Johannesburg, and Addis Ababa during the period January 1968 to June 1970. It reported an RMS error of 4.9 meters for the BC-4 worldwide passive satellite network which satisfied the U.S. geometric program accuracy goal of +10 meters. This same paper also introduced the concept of observations on an active satellite using Doppler techniques and a new Doppler geodetic signal receiver system called the "Geoceiver". A concept for extending a unified reference coordinate system throughout Africa, using the Geoceiver, was then introduced.

In the 9 years since the above announcement of the Geoceiver's capability to achieve accurate geodetic control virtually anywhere on the earth, about 137 African points have been submitted to our files at DMA. Not all of these Doppler geodetic stations are situated on geodetic triangulation or traverse

control stations and for some other, that are on control, the locations are not clearly defined. During this period, DMA has also acquired and collected about 3,400 Doppler positions located throughout the world, mostly through international collaboration with other nations.

The Doppler geodetic survey procedure utilizing our precise ephemeris has essentially become the international standard for high-accuracy survey point positioning and can be utilized to unify the geodetic datums of the African Continent. Doppler control established through utilization of our precise ephemeris has an expected accuracy of 1 meter, or better, in each of the three coordinates. In our opinion, the ^{Minimum} ideal number of Doppler points required for establishing datum relationships or computing the essential transformation parameters between two coordinate systems is three per datum. However, an optimum configuration of such Doppler control is always a subject of detailed planning and DMA is most willing to discuss each case with the concerned African countries' national survey organizations. These cooperative projects will benefit our efforts towards improvement of a unified World Geodetic System (WGS) by 1984.

The initial DMA concept plan for unification of the Africa geodetic datums is shown in Figure 1. Large-scale graphics and other details in this respect will be made available to country representatives upon request. Our plan identifies the minimum number of sites needed to obtain a set of datum shifts for incorporation in a post-80 WGS solution. Direct connection to local geodetic control is the primary and essential aspect in this unification plan.

Figure 2 builds on the ground control connection plan. It proposes a chain of Doppler points encircling the continent along the seacoasts. Doppler points on the seacoast are needed by DMA for the post-80 WGS to correlate with an ocean geoid incorporating satellite radar altimeter measurements of sea surface topography. Accurate orthometric heights and/or gravimetric undulations at these

Doppler stations (designated DGPAC in Figure 2) are additional features of the plan. We would also suggest the participating African nations initiate, if not already started, their long-term needs for tide gauges and tidal measurements. We believe that DGPAC sites may also serve two other important applications: as Hydrographic chart control and localized datum points in areas where the geodetic network is underdeveloped.

Doppler point positioning can also be utilized to establish a zero order net. In those areas lacking geodetic control, Doppler points can be established to form a basic framework, or zero order net, from which conventional control can be extended. To tie the zero order net to the local or national datum, at least one Doppler position must be established on control nearby; this same point will also contribute to the post-80 WGS solution.

Doppler sites can thus, if properly planned, be used to meet several needs in addition to that of datum unification. Technical inquiries from all African countries are invited to initiate cooperative Doppler campaigns.

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Figure 1.

Doppler Datum Unification Sites

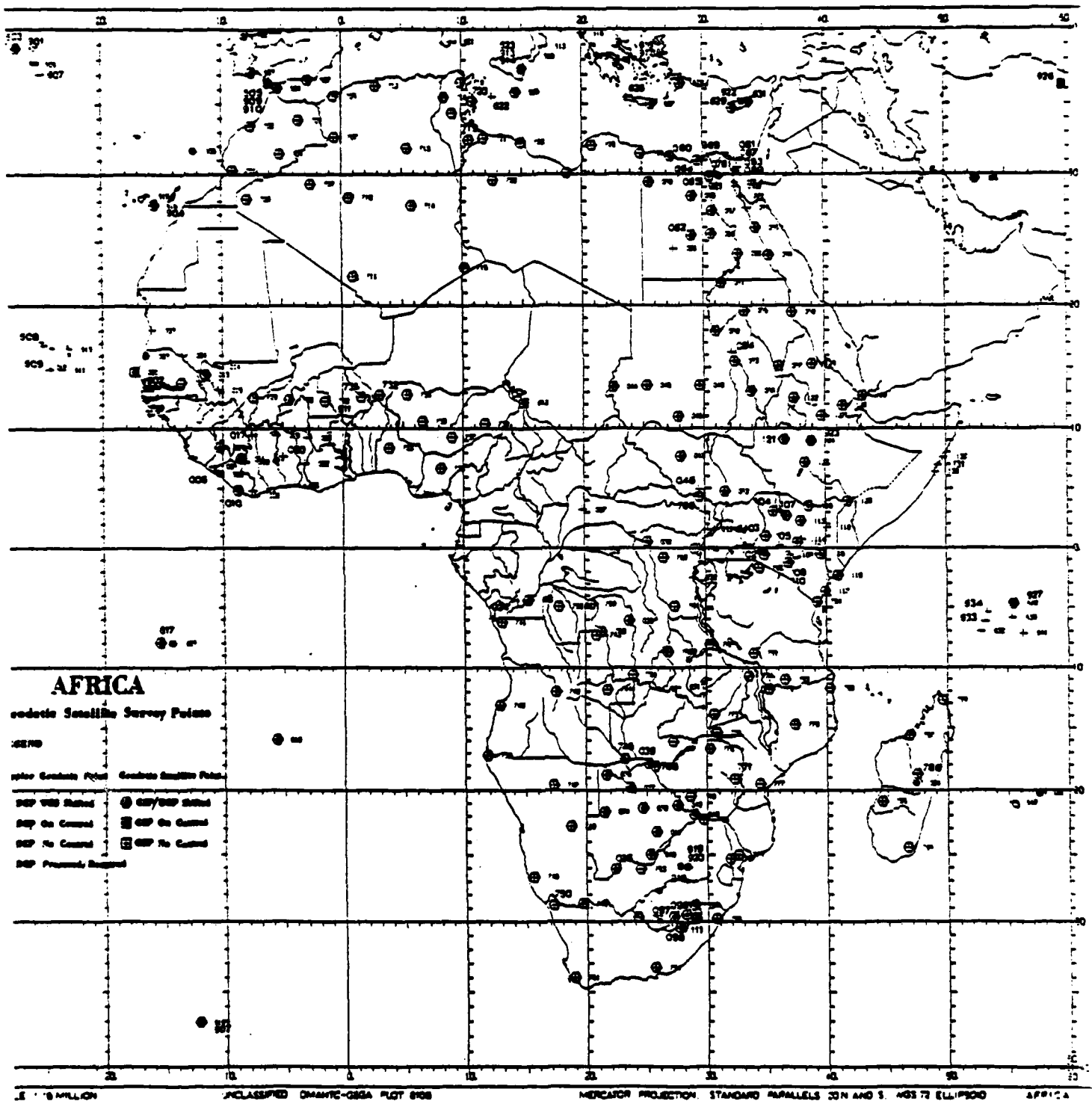


Figure 1

Figure 2.

Doppler Altimeter Calibration Sites

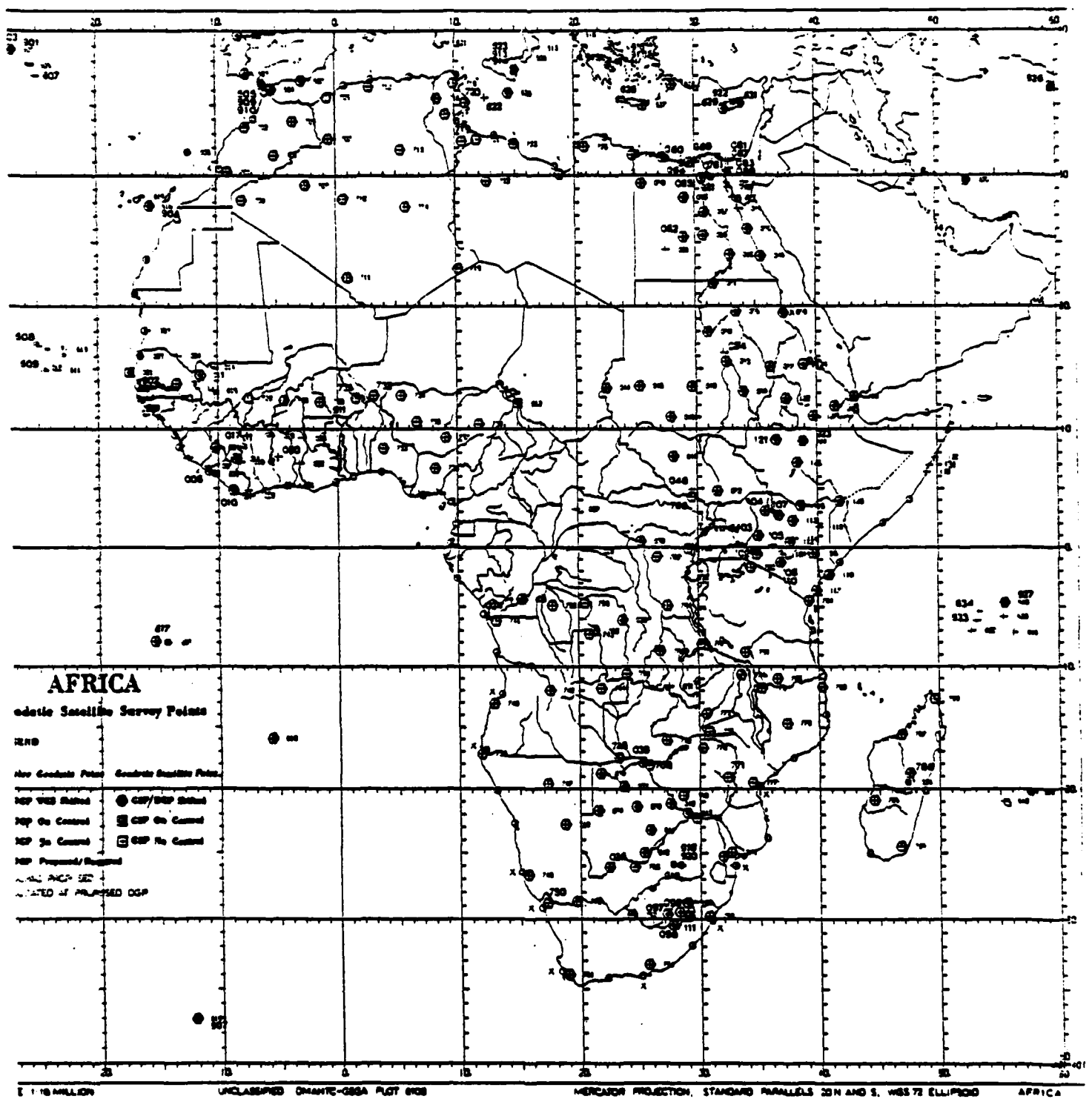


Figure 2 Prelim.